Development Status of Cassini Radar for Remote Sensing of Titan

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ABSTRACT

Cassini Radar **is** a multimode radar instrument designed **to** probe the optically inaccessible **surface of** Titan, Saturn's largest moon. The individual modes **will allow** surface imaging, surface topographic and backscatter measurements, as **well as the** sui face emissivity measurements. Recently, the breadboard model **of (his** instrument was built and has undergone a **series** of functional and performance **tests.** The results obtained **from** these **tests indicate that** the instrument **design is** satisfactory and that the various **required** performance parameters are sufficiently met.

1. INTRODUCTION

Cassini Radar **is one** of the science **instruments for** the Cassini **Mission - a joint** NASA/ESA **mission** to **carry out** detailed study of Saturn and its **many** satellites **in early 2000s. Tbc** Cassini spacecraft **will** be launched **in 1997 and will begin orbiting** Saturn **in 2004. In** order **10** study the surface properties and processes **of** Titan, the largest satellite **of** Saturn, the spacecraft **will** make a number **of** close **flybys** of Titan **during** its 4-year **mission.** During these **flybys,** the Cassini Radar and other **instruments** onboard the spacecraft **will** conduct intense observations. Cassini Radar **is designed** to operate **in four** observational **modes** at spacecraft altitudes **below 22500 km on** both **inbound** and **outbound** tracks **of** each hyperbolic **flyby** of Titan. They **include:** the **imaging mode** which provides medium-to-high resolution imaging, the altimeter **mode which** measures **tbc** relative surface elevation **of tbc** suborbital tracks, the scatterometer **mode** which measures Titan's sui face backscatter coefficients, and the radiometer mode which measures the sui face emissivity **of** Titan as an adjunct to the active radar measurements throughout the entire pass. This mode **multiplexing** strategy **is** graphically illustrated **in** Fig. 1.

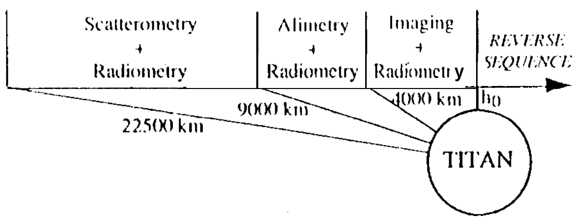

Figure 1. Observational **modes** used **by** the Cassini Radar and **their** operational range during a Titan **flyby.** The spacecraft altitudes **during** the **closest approach** (h_0) **range** between **950** km and **2800 km** in different **flybys.**

Cassini Radar instrument **is** developed **jointly** between NASA/JPL, Italian Space **Agency** and its contractor, Alenia Spazio **(Al. S). Tbc** flight instrument **consists 01** four major components: the Radio-**Frequency** Electronics Subsystem (RFES), the Digital Subsystem **[[)SS),** the **Energy** Storage Subsystem **(. ESS),** and the Ku-band antenna **(ANT). After two** years **of design** and development, the Cassini Radar **design** configuration has been finalized and the breadboard **model** has **been** implemented. Detailed functional and performance tests **of** the breadboard **model** was **conducted in** the first quarter 1994 and the breadboard **test** results **will** be **used to** guide the **subsequent design** modification and fabrication of the flight **unit. In ibis** paper, **wc** discuss the functionality, performance parameters, and the instrument configuration of **ibis** sensor. Recent breadboa**d** testing results are also presented.

2. RADAR MODE DESCRIPTION

Tradeoffs made between atmospheric **absorption,** measurement **resolutions.** and detection sensitivity have led **In** the selection **of** 13.78 GHz as the radar operating frequency. Due **10** the weight and **volume** constraints, the Cassini Radar **will usc** the spacecraft's **big b-**gain, **4-m** telecommunications antenna **during** radar **operation. 1"0** extend the imaging coverage, a **multiple** radar **feed** structure will be mounted on the antenna reflector to generate **five** antenna **beams** that are adjacent to **onc** another **in** the **cross-reck** dimension. **This** beam **configuration is** graphically illustrated **in** Fig. 2.

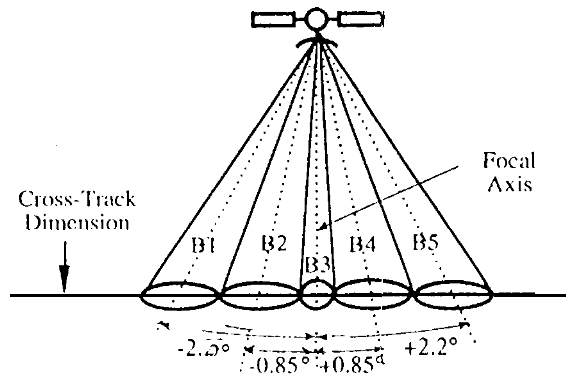

Figure 2. Antenna beam configuration for the Cassini Radar

The motivation for the Cassini Radar multimode **design is** to be able to accommodate the potentially different types of surfaces on Titan. **Given** the uncertainties in ephemeris and radar backscatter, the RADAR system performance must be robust. **Since** the radar range **will** be constantly varying within a single Titan flyby pass as **well** as from pass to pass, **ibc** radar parameters, such as pulse width, bandwidth, receiver **gain.** pulse repetition frequency and other timing parameters, must **bc** updated at regular intervals **in order** to maintain sufficient **sicllal-in-noise** ratio **on** the radar echoes. The key system parameters for each radar mode **arc** listed **in** Table **1.**

Parameters	Imaging	Altimeter	Scatterometer	Radiometer
Frequency (GHz)	13.78	13.78	13.78	13.78
Peak power (W)	63	63	63	63
No. of beams	All 5	Beam 3	Beam 3	All 5
Look angle (deg):				
Cross-track	5 to 20	0	±6 to ±12	±6 to ±12
Along-track	0	0	±6 to ±12	±6 to ±12
PRF (KHz)	1.8 to 6.0	4.7 to 5.6	1.0 to 3.0	N/A
Pulse width (μs)	200 - 400	150	500	N/A
Bandwidth (KHz)	425, 850	4250	106	100,000

Table 1 System parame ers for th Cassini Radar modes.

Relatively large uncertainties in the spacecraft ephemeris and attitude predictions **arc** anticipated and have **led to** a **"burst timing" design** for signal transmission and reception. In **Ibis** timing approach, the radar transmits a series **of pulses for** a time period and **is** then switched to receive the return echo burst. After reception, **tbc** radar switches to the radiometer mode to collect the surface radiation measurements.

With such an approach, the uncertainty in timing due to ephemeris and pointing errors will be accommodated by adjusting the burst period and receive data window. Various radar modes will utilize different burst timing parameters 10 maximize the science data collection. In this section, a brief overview on each radar mode is given. A more detailed description can be found in Im *et al* (1993).

2.1 Imaging Mode

During radar imaging, the spacecraft will rotate to either the left or the right side of the sub-satellite track according to the pre-determined command sequence, and all five radar antenna beams will bc utilized one at u time to obtain the maximum possible cross-track swath coverage. The total cross-track swath created by combining the five illuminated sub-swaths ranges from -120 km at spacecraft altitude of 1000 km to -460 km at spacecraft altitude of 4000 km. During a close flyby with ho ≤ 1250 km, the Cassini Radar can image up to - I. I % of Titan's surface.

The image azimuth resolution will be accomplished by unfocused SAR processing of the echo bursts. For the burst-timing scheme to be used by the Cassini Radar, the azimuth resolution is estimated to be between 350 m and 720 m throughout the imaging period during each flyby. The image range resolution will be accomplished by range compression of the linear FM chirp signals and is proportional 10 the signal bandwidth and the angle of incidence. In the current design, a 850-KHz bandwidth will be used when the spacecraft altitude is 1600" km or less, and a 425- KHz bandwidth will be used at spacecraft altitude between 1600 and 4000" km in Order to enhance the SNR. The corresponding range resolution is estimated to be between 480 m and 640 m at h ≤1600 km, nod between 420 m and 2.7 km at 1600 km <h ≤4000 km.

Based on the designed radar parameters and the viewing geometry, the thermal SNR of the imaging signal is estimated to range between 14 and 40 dB for a surface backscatter cross-section value of unity.

2,2 Altimeter Mode

This mode will bc used to study the relative topographic change of Titan's surface along the sub-satellite track. Operating at spacecraft altitudes between 4000" km and 9000 km, this mode will utilize the central, nadir-pointing antenna beam (Beam 3) for transmission and reception of chirp pulse signals at a system bandwidth of 4.25MHz. The altimetric measurements collected are expected to have horizontal resolutions (pulse-limited radar footprints) ranging between 24 km and 27 km, and vertical resolutions of about 50 m. Given such vertical resolution nod the anticipated spacecraft navigation and pointing uncertainties, we estimate the overall relative height measurement accuracy to be of the order of 150 m.

2.3 Scatterometer Mode

This mode is intended to map the radar reflectivities of the potentially different types of Titan's surfaces at different incidence angles. This mode will operate at altitudes between 9000 km and 22500 km and will require spacecraft maneuvers to scan the central antenna beam over the entire Titan disk. To ensure sufficient signal detection, a smaller bandwidth of 106 KHz will bc used by this mode. Both surface backscatter and noise-only measurements will be collected with Ibis mode so that the surface σ_0 can be estimated accurately. Depending on the range distance, this mode can detect surface backscatter coefficient values as low as -.35 dB.

2.4 Radiometer Mode

The objective of the radiometer mode is to measure Titan's surface emissivity at 13.78 GHz. The data collected will bc complementary to those collected by the active radar modes since it provides an additional input into the radar backscatter models. The radiometer mode will operate at a bandwidth of 100" MHz. When operating in conjunction with the scatterometer mode, this mode may use up 10 all five beams in order to increase the surface coverage. Cold-space, hot-load and cold-load calibration procedures are included in the Radiometer mode in order to improve the temperature measurement accuracy. Our preliminary estimate shows that the surface radiated temperature can be measured to within ±3K.

3. RADAR INSTRUMENT DESIGN

A simplified functional block diagram for the Cassini Radar is shown in Fig. 3. As mentioned before, the radar consists of four major components: the Digital Subsystem (DSS), the Radi - Frequency Electronics Subsystem (RFES), the Energy Storage Subsystem (ESS), and the Ku-band antenna. The DSS interfaces to the Cassini spacecraft through the high speed science data bus to receive commands and timing information and provides for storage the science and engineering data from the instrument. individual subsystems receive spacecraft power during radar operation.

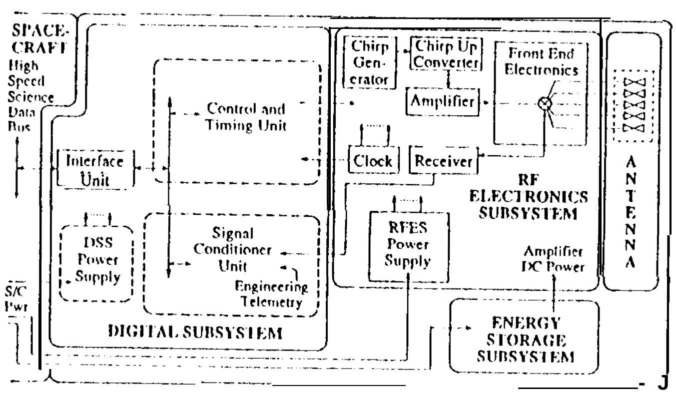

Figure 3. The Functional block diagram for the Cassini Radar.

The DSS includes the power supply, an interface unit, a control and timing unit, and a signal conditioner unit. The power supply receives the spacecraft 30 VDC power and converts this 10 the voltages used by the digital units. The interface unit includes a spacecraft bus-to-radar inter face and a computer which receives both the radar operating software nnd an instruction table which is used to operate the radar during an operational sequence. The control and timing unit acts upon the received instructions and sets the timing of all the events in the radar such as the pulse bandwidth, duration, repetition rate, receiver bandwidth, receive window, and radiometer integration period. All the functions in the RFES and the other portions of the DSS are controlled through the control and timing unit. The signal conditioner unit receives the science data and the engineering telemetry data in analog form and converts these signals to digital form before sending the data to the flight computer where it is packetized for transmission to the spacecraft.

The RFES performs most of the analog functions of the radar. The system uses a linear FM chirp whose bandwidth, duration and offset are determined by signals from the control and timing unit to a digital chirp generator. The chirp is then upconverted to the Ku-band radar frequency. The amplifier is a traveling wave tube amplifier which receives conditioned power from the ESS. The amplifier is coupled to the antenna through the front end electronics which contains the switches usc(l 10 select the appropriate beam. The receiver contains the down conversion electronics and four selectable bandwidth filters in addition to the wide bandwidth radiometer circuitry. The receiver sends video signals to the DSS for digital conversion. The clock from which all timing signals are (lcl ived is provided by an ultra stable oscillator.

The ESS performs the functions of a battery in that it supplies the short term high DC power required by the amplifier while reducing the short term load to the spacecraft. The spacecraft has no battery and thus cannot accept short duration high D(' power loads. The ESS uses a combination of DC-DC converters and capacitors 10 even the load to the spacecraft power bus.

The Ku-band radar antenna is the shared 4-m diameter science-telecommunications antenna. The radar antenna has five separate horn feeds near the focal point of the antenna at its base. The pulses ret'lcct off of a frequency selectable subsurface behind which are located two of the four antennas frequencies before being reflected off the main antenna surface.

4. BREADBOARD TEST RESULTS

In a previous paper (Hensley *et al.*, 1993), we have investigated the Cassini Radar antenna performance and its impacts on SAR ambiguities. To demonstrate the radar electronics design concept and 10 assess its functionality and performance in realistic settings, the breadboa rd model for the RFES, DSS, and ESS has recently been developed and test data were collected and analyzed. In particular, the test data were used 10 study the radar timing performance, the characteristics of the chirp signal used by various radar modes, the calibration source stability, and the impulse response of the instrument.

The test dala (digitized pulses) for a given con figuration of radar parameters were grouped in the same file. Each file consists of between 20 and 200 pulses. After appropriate normalization, the statistics on a given performance parameter of the data in individual files were displayed side-by-side for cross-comparison. For instance, Fig. 4 shows the test results of the difference between the measured and the expected chirp pulse duration, and Fig. 5 shows the test results of the difference between the measured and the expected chirp bandwidths for the various radar modes. The chirp pulse duration was varied over the range of 200 and 500 microseconds. The chirp bandwidths of 4250, 850, 425, and 106 KHz used during these tests correspond to the bandwidths to bc used by the altimeter, high-resolution imaging, low-resolution imaging, and scatterometer modes (see Table I). The test data were sampled at slightly above the Nyquist sampling rate. We can see from these two figures that the random measurement errors and the system biases are reasonably small and the performance parameters measured at higher sampling rates are very closed to their expected values. On the other hand, the scatterometer test data, which wet-csamplcd at the lowest rate of 250 KHz, exhibit considerably larger randomness in both the pulse duration and bandwidth statistics duc to larger sampling errors. Nevertheless, the performance of the test data of all four modes meet the requirements (shown as the dotted lines) with comfortable margins.

We have also conducted other performance tests with this breadboard model, including pulse amplitude, pulse droop. noise level, amplitude and phase variations, compressed pulse mainlobe response, peak and integrated compression sidelobes, timing jitter, and lint- and cold-load stability tests, etc. The results of these tests have all been satisfactory. Such results indicate a viable Cassini Radar design and verify the functionality and the performance of the multimode radar operations.

5. SUMMARY

The Cassini Radar is designed 10 have a wide range of capabilities in order to encompass a variety of possible surface properties of Titan. In this paper, we presented an overview of the various radar modes for imaging, altimetry, scatterometry, radiometry data acquisition, a summary of the instrument design, and the recent breadboard test results. In general, the test results have verified the multimode radar performance and have suggested that the Cassini Radar design is -viable. Cassini Radar is currently moving into the flight model development phase and a fully -integrated flight model is expected to be completed by early 1996.

ACKNOWLEDGMENT

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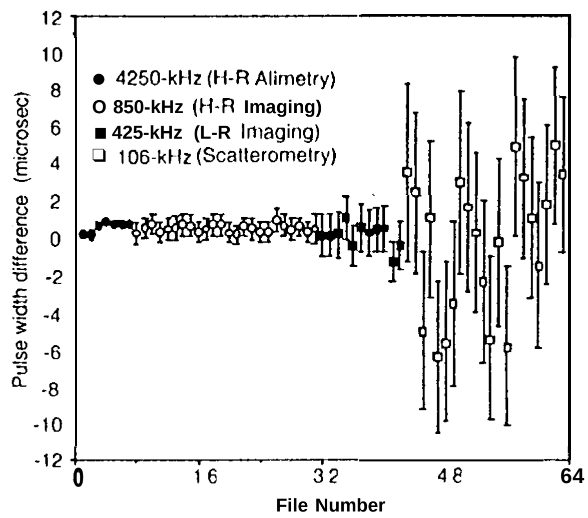

Figure 4. Breadboard pulse duration test results.

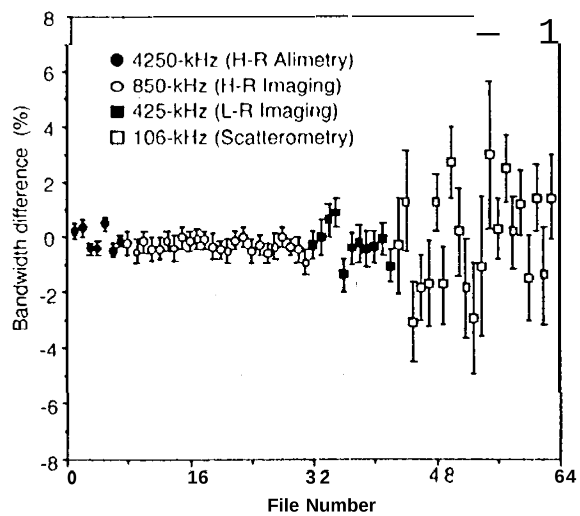

Figure 5. Breadboard bandwidth test results.